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PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT: DANIEL N. KARPEN

TITLE: MAGNETICALLY SHIELDED FLUORESCENT LAMP BALLAST CASE

SERIAL NUMBER: 09/096,999

GROUP ART UNIT: 2817

FILED: June 13, 1998

EXAMINER: DAVID VU

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DECLARATION UNDER RULE 132 AND RULE 131

Honorable Commissioner
Washington, D. C. 20231

Dear Sir:

I, DANIEL KARPEN, a citizen of the United States residing at 3 Harbor Hill Drive, Huntington, N. Y. 11743, do hereby declare as follows:

I am a registered professional engineer, license number 64966, registered to practice engineering in New York State.

I am the inventor of the invention claimed in the above identified application.

The following is submitted by me in order to demonstrate the superior results of the magnetically shielded ballast case as set forth in the claimed invention, and to distinguish the present invention from the prior art of Blocher (U. S. Pat. No. 5,446,617, filed 5/13/94, issued 8/29/95) cited by the examiner.Under Rule 131 I also pre-date Blocher's filing date.

The patent application is a major advance in fluorescent lighting technology, solving a significant human factors problem, from both core coil and solid state fluorescent ballasts.

I am making this declaration to show that the problem of electromagnetic fields from fluorescent lighting, particularly the magnetic component of the electromagnetic field, is a problem that I have experienced for a number of years.

I went to elementary school at Lloyd Harbor School, in Huntington, New York, from 1955 to 1962. My elementary school had incandescent lighting at that time.

In eighth grade, the school district opened a new high school, and my French teacher noticed that I was daydreaming in class much of the time. I did not know why I was daydreaming, but I could not pay attention very well. The school opened just after the beginning of 1962.

From 1970 to 1973, I attended the State University of New York at Stony Brook studying graduate mathematics. At that time I realized that the fluorescent lighting at the university was causing me a great deal of difficulty, and I found it difficult to study.

From 1974 through 1982, I had a number of jobs, and I found it necessary to have office space without fluorescent lighting as the fluorescent lighting was giving me headaches at work.

From 1982 through 1986, I worked out of my own house. In 1986 and 1987, I had a position with the New York City Human Resources Administration. I was about that time that high frequency electronic ballasts began to be introduced into the market place.

In 1978, I read an article in Environment magazine on the effects of electromagnetic fields on humans. I decided to do a very simple experiment. While walking up Beech Hill Road, I found that if I walked on the same side of the street as the power lines, I could "feel" them, but if I walked on the opposite side of the street, I could not feel them. I have attached a copy of this article to the end of this declaration.

From 1987 to the present, I have worked out of my house. During that time, I have done energy conservation consulting, recommending the use of solid state ballasts as an energy conservation measure.

From 1990 through 1993, I specified a solid state ballast manufactured by ETTA Industries. The electromagnetic fields from this brand of ballast were low enough that the average person could not feel them.

On January 2, 1991, I purchased a hand held magnetic field meter from Real Goods Trading Corporation. With this hand held instrument, I was able to measure the magnetic component of the electromagnetic field in the extremely low frequencies and very low frequencies (ELF and VLF). I had previously seen these meters at an office products trade show in New York City in May, 1990.

The Safe Meter TM, manufactured by Safe Computing Company, has two scales to measure ELF (20 to 2,000 Hertz) and VLF (2,000 to 400,000 Hertz). With this instrument, I began measuring in milligauss, a unit of magnetic field strength, everything and anything I could find.

I was able to measure the magnetic fields from fluorescent lighting, power lines, computers, refrigerators, motors, and other electrical and electronic equipment.

In September, 1993, I had a problem with high electromagnetic fields from air cooled dry type transformers located throughout a high school in Suffolk County where I was doing some consulting work. I contacted Richard Knadle, a friend of mine and an electronics engineer at Airborne Instruments Laboratory in Deer Park, New York, what to do about the problem. He told me that there were materials such as mu-metal, and Co-Netic and Netic magnetic shielding alloys that could shield the magnetic fields. Richard Knadle told me whom to contact for more information, and he gave me the name of the local technical sales representative, Bob Smith, who works for Perfection MIca Company. A copy of my telephone notes from that time is attached to this declaration.

After a series of telephone calls, I was lead to a Tony Cardenas, who knew how to design shielding enclosures for transformers, and other electrical and electronic equipment. I contacted Tony Cardenas on or about September 15, 1993, and I sent him information about my full-spectrum polarized lighting system. A copy of the letter is attached to this declaration.

Thus, at that time, I immediately knew that the solution to the problem of magnetic fields from fluorescent ballasts was to shield the ballast with a shielding material such as Co-Netic, Netic, or mu-metal. I knew about this solution in September, 1993, and did not tell anyone I spoke to at the time.

Shortly afterwards, in the fall of 1993, I obtained literature from Perfection Mica Company, the supplier of the Co-Netic and Netic shielding alloys. I also obtained samples of the Co-Netic and Netic shielding alloys from the Perfection Mica Company through Bob Smith. I did some experimentation, and I placed the alloys against the side of a strip fluorescent fixture, at the location of the fluorescent ballast. When I did that, my headaches, tiredness, fatigue, and sleepiness from fluorescent lighting went away. In order to isolate the effects of the magnetic fields, I did my experiments with a narrow wooden box around the lamps of the fluorescent fixture, so no light or glare would get out. I did these experiments in the basement of my house, with all other electrical equipment in the house turned off.

Thus, one of the problems of fluorescent lighting, the emission of magnetic fields from the electrical and electronic components inside a fluorescent ballast, with its resultant human factors effects, is alleviated with the use of magnetic shielding alloys as a component in the ballast case.

It should be noted that Blocher '617 electrically grounds the fluorescent ballast, whereas my patent magnetically shields the fluorescent ballast. The art of electrically grounding is much different from the art of magnetically shielding an object. See the attached chapter 109 entitled "Grounding and Shielding", taken from The Engineering Handbook, edited by Richard C. Dorf, published by CRC Press (1996). The types of materials are different; the equations used for the calculations are different.

The patent of Blocher '617 is for "A ballast circuit and grounding structure for electrically grounding a ballast circuit to a housing and for capturing transmitted RFI and EMI therefrom." (taken from first sentence of abstract).

My patent is for "A magnetically shielded fluorescent lamp ballast case for shielding human beings from the negative effects of magnetic fields emanating from a fluorescent lamp ballast is made of a ferromagnetic alloy, or lined on the inside or outside of the fluorescent lamp ballast case with such foil alloys." (taken from first sentence of abstract).

In "Grounding and Shielding", page 1182, under the heading "Shielding Materials", it reads:

> "As shown in Fig. 109.10, good shielding efficiency for plane waves or electric (high impedance) fields is obtained by using materials of high conductivity such as copper and aluminum. However, low-frequency magnetic fields are more difficult to shield because the reflection and absorption loss of non-magnetic materials, such as aluminum, may be insignificant. Consequently, to shield against low-frequency magnetic fields, it may be necessary to use magnetic materials."

In summary, the present invention is a necessary and needed invention, solving a long sought unrecognized need; it solves once and for all the problem of magnetic fields being emitted from fluorescent lamp ballasts. Others have not come up with such an invention.

It is respectfully submitted that the present patent application is in a state where the claims as presented are allowable, which allowance is ernestly solicited.

I diligently worked on the subject matter of the present invention, in that as noted above I conceived of my invention prior to the May 13, 1994 filing date of US patent no. 5,446,617 of Blocher. I filed a Disclosure Document no. 387,572 on June 26, 1995, (copy of which is attached) continued to work on the subject matter of my invention and subsequently filed a parent patent application on February 12, 1996 under serial no. 08/600,400.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Daniel Nathan Karpen

Daniel Nathan Karpen

Dated: July 29, 1999

PAT131

List of Exhibits

Exhibit A	Applicant's Disclosure Document no. 387,572 of 6/20/95
Exhibit B	Young, Louise, "Danger: High Voltage", Environment magazine, May, 1978, pp 16-38
Exhibit C	Real Goods Trading Corporation, invoice to Applicant no. 61208 dated 1/2/91 for Magnetic Field Meter, Model no. 57-103
Exhibit D	letter of Applicant to Tony Cardenas dated 9/15/93
Exhibit E	Applicant's handwritten telephone notes of September, 1993
Exhibit F	Duff, William G., "Grounding & Shielding", The Engineering Handbook, CRC Press, IEEE Press, copyright 1996, pp 1176-1185

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT:	Daniel Karpen
SERIAL NO.:	08/600,400
FILED:	February 12, 1996
EXAMINER:	D. Vu
MAILING DATE OF ACTION:	Sept. 4, 1997
GROUP ART UNIT	2502
TITLE:	ELECTROMAGNETICALLY SHIELDED FLUORESCENT BALLAST

DECLARATION

I, Daniel Karpen, hereby declare:

Attached hereto is a copy of my Disclosure Document no. 387.572 filed June 20, 1995, which is referred to on page 1 of the specification.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Daniel Karpen

Daniel Karpen

Dated: November 25, 1997
b:ballastdisdocu

DISCLOSURE DOCUMENT NO.

387572

FILING FEE: $10.00

RETAINED FOR 2 YEARS

THIS IS NOT A PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK

Inventor: Daniel Karpen
3 Harbor Hill Drive
Huntington, N. Y. 11743

Invention Title: ELECTROMAGNETICALLY SHIELDED FLUORESCENT BALLAST

Commissioner of Patents and Trademarks
Washington, D. C. 20231

Sir:

INVENTION DISCLOSURE DOCUMENT

In connection with the above-captioned invention, please consider herewith the attached disclosure document.

The inventor, Daniel Karpen, hereby affirms that he is the sole and original inventor of the within described invention. Two copies of the Disclosure Document are enclosed herewith, one being for date-stamping and to return to the inventor. A return postcard is also herewith enclosed.

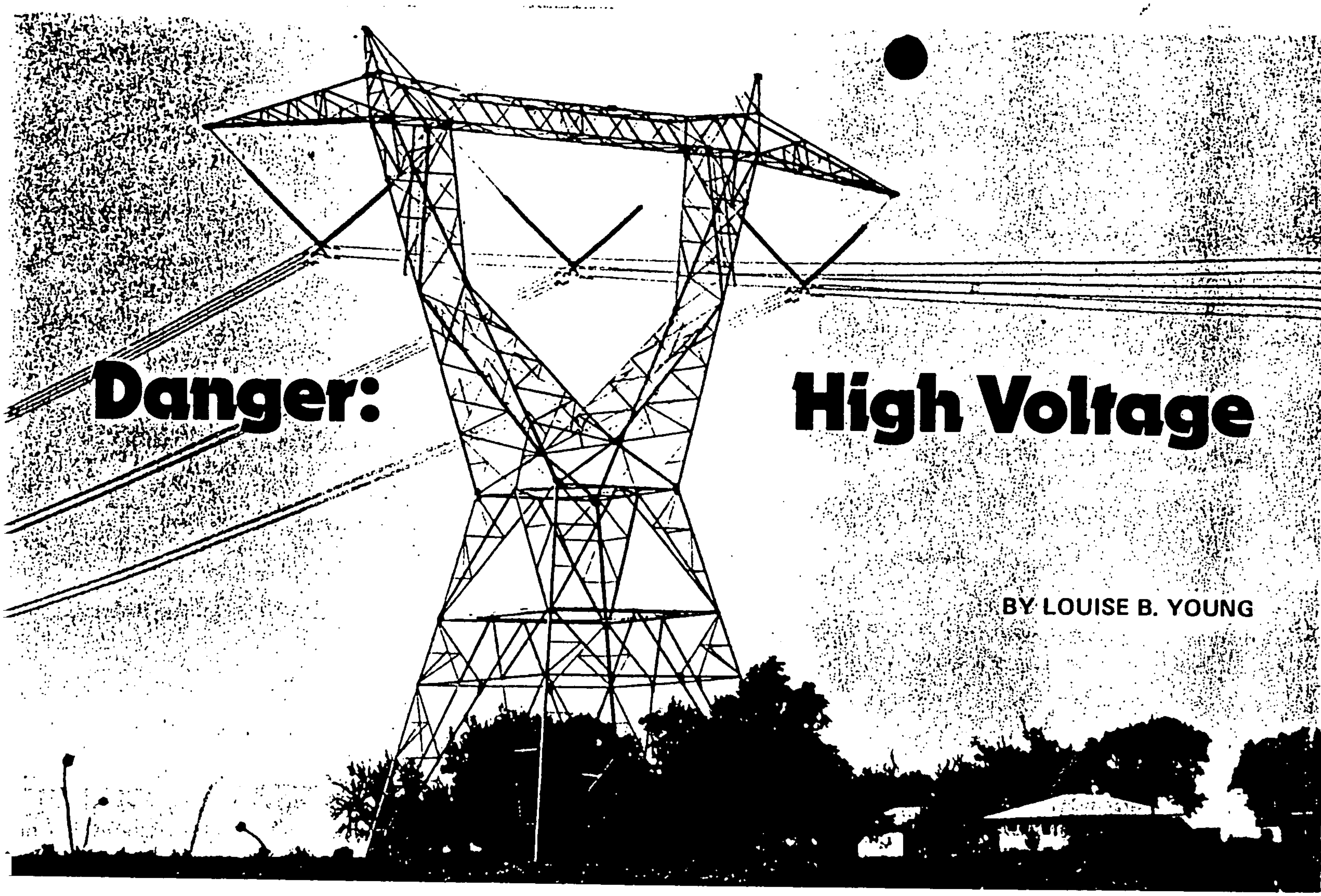
6/26/95
Date

Daniel Karpen
Daniel Karpen

ELECTROMAGNETICALLY SHIELDED FLUORESCENT BALLAST

An electromagnetically shielded ballast has a ballast case made of Co-Netic or Netic iron-nickel or iron alloys. The ballast case saturates the electromagnetic fields.

There is a reduction of headaches, eyestrain, fatigue and blurred vision by reducing electromagnetic fields. Present ballast technology, including solid state and electronic ballasts, have magnetic components such as inductors and transformers that produce electromagnetic fields. The present invention provides shielding to reduce the electromagnetic fields below that measurable by hand held gaussmeters.



Danger: High Voltage

BY LOUISE B. YOUNG

MASSIVE RESISTANCE TO THE CONSTRUCTION of very high voltage power lines has been developing recently throughout the United States and has taken the electric industry by surprise. For many decades transmission lines went through without any effective opposition. Approval by the public utility commissions was virtually guaranteed. Landowners who resisted appropriation and were taken to court were unable to prevent the taking of their land.

What has caused this sudden violent opposition? The new factor is the emergence of health and safety questions about the extremely high voltage lines. Voltage has doubled and then doubled again in recent years, and concern has grown with the increase in voltage. The largest transmission lines built before 1950 carried 138 or 230 kilovolts. In the 1950's the next generation of transmission lines were designed carrying 345kv. All of these lines transmitted alternating current (AC). In the late 1960's the first line carrying 765kv AC and one carrying 800kv DC (direct current) were put into service. It is these high voltage lines that are creating the most vigorous protest; 500kv AC lines (several of these often run in tandem) are also being opposed by landowners. Lines of this voltage are more common in the western states while the 765kv lines have been installed mainly in the midwest and east.

The presence of a big transmission line across farmland has always caused some inconvenience and danger for the people who live and work around the lines. Cultivating and planting around towers is more difficult than on unobstructed land. If a broken conductor falls to the ground, a

current flows through the earth for a brief interval of time. A voltage appears in the vicinity of the nearest tower, creating a life-threatening situation for anyone standing nearby. Lightning strikes pose a similar hazard to a person standing near a tower during an electric storm. Under transmission lines irrigation systems must be used with special care. If a solid stream of water touches a conductor, a short circuit can occur, posing a very serious danger for anyone touching or operating the equipment. Although most irrigation systems do not deliver a solid stream of water, sprinkler heads may blow off, causing a high pressure steady stream to shoot high up into the air. Furthermore, certain large gun-type systems currently in use are capable of directing a steady unbroken stream to within close proximity of the conductors.[1]

In the vicinity of high voltage lines children must be carefully supervised. The rights-of-way are not fenced and the towers provide tempting ladders to the sky. The flying of kites or model planes around a transmission line can have catastrophic results, as demonstrated by the fire that occurred last summer when a young man flew his kite into an electric line near Los Angeles. The kite became entangled in the conductors and created a short circuit, setting off a fire that did over a hundred million dollars worth of damage.

In recent years the maintenance of rights-of-way with herbicides sprayed from planes or helicopters has added a new dimension of concern. Across certain types of land, the United States Environmental Protection Agency permits the use of several herbicides including 2, 4, 5-T for vegetation control of rights-of-way.[2] This herbicide contains a contaminant, dioxin, which is extremely toxic and has been shown to cause birth defects in laboratory animals.[3]

Current Hazards

These hazards are common to all transmission lines, large and small, but the voltages carried by the latest generation of transmission lines are so great that they cause small electric currents to flow continuously in the ground and vegetation as well as in the bodies of animals and people who walk or work around the right-of-way. In some cases electric charges build up on metallic objects. If these objects are insulated from the ground (by rubber tires, for instance) and a person who is making good contact with the ground touches the charged object, the charge flows through him to ground. Under a 765kv transmission line these shocks are sometimes strong enough to produce a sudden jerk which can cause a person in a precarious position to lose his balance or to come into contact with moving parts of the farm machinery.

If the charge is large enough, it can paralyze the muscles of the hand so that the person is unable to let go and the current continues to flow through his body. The thresholds at which this paralysis occurs are smaller for a woman than for a man and smaller still for a child. Measurements made by electrical engineers under 765kv transmission lines show that very large vehicles, such as school buses, tractor-trailers, or large combines, can deliver enough current to exceed the safe let-go threshold for a child.[4] Although such an accident is unlikely, it is possible. People carrying metal pins or plates in their bodies and people wearing pacemakers are particularly apt to sustain dangerous shock currents around high voltage lines.

A spark often accompanies these discharge currents and under just the right conditions it is possible for the spark to ignite a tank of gasoline. People should be warned never to refuel a vehicle under a big transmission line.

Pacemakers

A study recently completed at Illinois Institute of Technology Research Institute concluded that the most sensitive types of cardiac pacemakers would suffer interference from the fields routinely encountered under extremely high voltage lines.[5] The demand-type pacemakers (which constitute over 90 percent of the pacemakers presently being used) sense the contraction of the heart and do nothing when the heart is operating normally. When the beat does not occur within a certain period of time, the demand pacemaker emits a stimulating pulse. In order to respond to the normal heart beat, these pacemakers must be very sensitive and, therefore, are most subject to interference. The degree of response to an external electromagnetic signal is also affected by the geometry of the pacemaker and the way it is implanted in the body. The most vulnerable configuration is a monopolar demand pacemaker implanted in the abdominal area. The scientists conducting the IIT Research Institute study estimated that this type of implant represents about 3 percent of the total.[6] In addition, however, some of the pacemakers implanted in the pectoral region are sensitive enough to be affected by the electric fields encountered under the extremely high voltage lines. No estimate of the proportion of implants involved in this category was made but it appears to include a more common type of implant.[7]

When interference occurs, the demand pacemaker begins to put out a regularly spaced pulse which is not related to the patient's normal heart beat. Competition between the imposed and the natural rhythm may cause a serious problem, especially if it goes on for a considerable length of time. Thirty minutes was suggested by the consulting doctor on the IIT project as a reasonable estimate of the time required before the situation would become life-threatening. However, the report noted that doctors are not in complete agreement on this subject.[8]

Even if we assume that the 30-minute figure is correct, we can imagine many situations where a farmer working around a 765kv line could continue to be exposed for this length of time. A man planting or harvesting his crop under a 765kv line could very easily spend 30 minutes in electric fields which are intense enough to cause this interference to some types of pacemakers. Shocks from the metal bodies of farm machinery sustained during this time period would increase the risk.

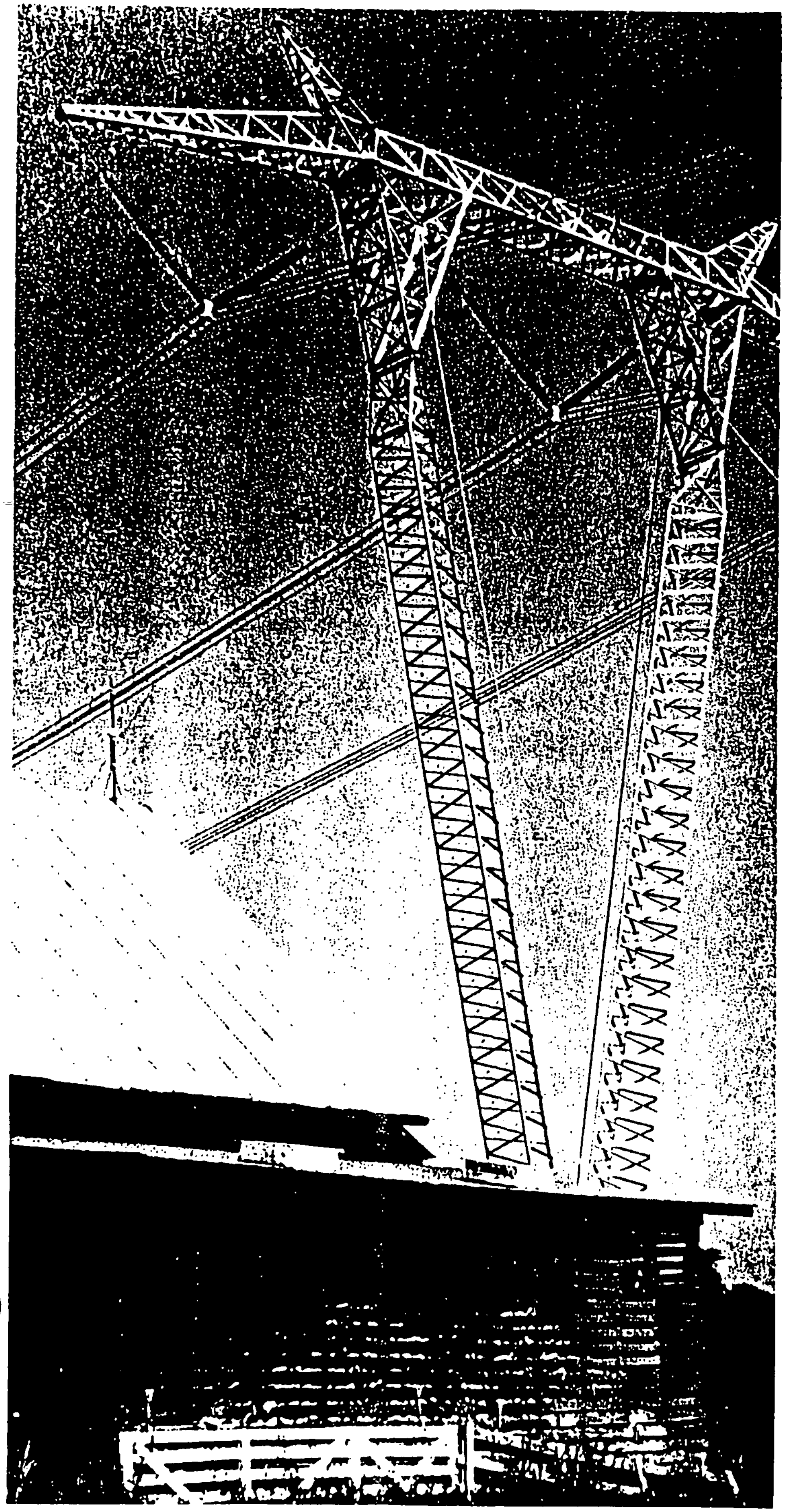
Louise B. Young is a physicist, editor, and science writer. Her most recent book is *Earth's Aura*.

Members of the general public who wear pacemakers can, of course, be instructed to avoid these hazards—to stay out from under big transmission lines and not to touch metal objects in their vicinity. People whose land is crossed by a 765kv line, however, cannot totally avoid risk without restricting the normal use of their property. Scientists employed by the electric companies stress the fact that the number of people at risk from these effects is relatively small. The precise combination of conditions which would cause death would not be likely to occur often. At the very least the hazards should be carefully explained to the individual who will be utilizing the right-of-way of a 765kv line. Property owners might be given the option of assuming this risk at a compensatory price or selling out at a fair price and moving away.

The point is frequently made that we normally accept many risks in our daily lives in order to enjoy the advantages that advancing technology has bestowed. But it is important to draw a distinction between risks voluntarily assumed in order to gain some benefit and risks that are forced upon people. Full disclosure of the risks and alternate options are necessary before the acceptance of the risk can be truly voluntary.

Long-Term Effects

A concern that has just recently come to public attention may prove to be the most serious hazard associated with extremely high voltage transmission. Several different lines of evidence suggest that regular exposure to the electric and magnetic fields experienced under the big lines (even without receiving any noticeable shocks) may cause long-term health effects. This possibility is particularly insidious because it gives no warning. It cannot be felt—like a spark discharge or seen—like a downed conductor or a lightning flash. The farmer whose land is crossed by a 765kv line exposes himself regularly to the electric



Several different lines of evidence suggest that regular exposure to the electric and magnetic fields experienced under high voltage lines may cause long-term health effects.

and magnetic fields without realizing that they may affect his health adversely.

The first evidence of this danger came from studies conducted in the Soviet Union. In 1962, after the first 500 kilovolt lines had been operating in the Soviet Union for several months, men working at the substations began to complain of headaches and a general feeling of malaise. Abnormal fatigue and sleepiness were mentioned by a majority of the workers.[9] They associated these symptoms with exposure to the electric fields.

A long-term study was made of these effects with systematic medical examinations of about 250 men working at 500 and 750 kv substations. These results were compared with medical examinations of men working at lower voltage substations. The investigation concluded that long-time work at 500 kv substations without protective measures resulted in "shattering the dynamic state of the central nervous system, heart and blood-vessel system, and in changing blood structure. Young men complained of reduced sexual potency."[10] The severity of these effects seemed to depend directly on the length of stay in the field. As a result of their findings the Soviets set up rules for exposure of their substation personnel to electric fields and they are currently conducting studies aimed at developing standards for exposure of the general public and people farming the rights-of-way.[11]

In the meantime, the use of the rights-of-way for 750 kv lines is restricted in Russia.[12] A zone about 360 feet wide centered on the line is limited to certain authorized uses and personnel only. It cannot be used for any recreational purposes or as places where people might congregate (transportation stops, collective vegetable farms, etc.). No buildings are allowed in this zone. Farmers are given special cautionary instructions. The crossing of a right-of-way is recommended near the towers. No vehicle or piece of machinery should be stopped or refueled under the line. If a mechanical failure occurs, the vehicle must be towed away. Metal shields must be used over the seats of farm machinery to reduce the strength of the electric field impinging on the farmer as he rides the machine.

The Soviet concern about the detrimental effects of regular exposure to strong electric fields is not shared by spokesmen for the electric industry in the United States. The reports of the Russian studies have been criticized as lacking sufficient quantitative data and precise clinical diagnoses. The reports are not as complete as scientific reports in the United States are expected to be. However, the fact that the Soviets have studied the health effects of electric fields for many years and have gone to considerable trouble to set up standards to protect their workers is convincing evidence that they believe this to be a serious problem.

In view of the questions raised about the Russian studies, it is surprising that there has been no serious attempt to repeat them in a manner that would be completely acceptable to the international scientific community. A thorough epidemiological study of electric utility workers and others who spend much time in strong electric and magnetic fields would go a long way toward answering the question of long-term health effects.

The only investigation of this general type ever conducted in the United States was a very small and inadequate study financed by American Electric Power Company. Starting in 1963 eleven linemen were given medical examinations over a nine-year period.[13] Contrary to the usual scientific procedure, no control group was used (a criticism that is frequently leveled against the Russian studies). No quantitative data was reported on length of time and level of exposure experienced by these men. No clinical information was reported. During the nine years one man dropped out of the study (because he quit his job). Eight of the other men became supervisors. At the end of the report a general statement was made that no significant changes of any kind were found in the general physical examinations. Three of the men did have abnormally low sperm counts in the last examination, but the counts had been quite varied throughout the study period and, therefore, it was concluded that "it would be hazardous to draw any conclusions, particularly from this small sample."[14] Indeed, the small number of men studied is the most serious flaw in this whole experiment. The sample is too small to yield any reliable information about subtle, long-term health effects such as those reported in the Russian studies.

Experimental Evidence

Although the interest in this problem is relatively new, there are on record at least one hundred other studies on the biological effects of electric and magnetic fields at power line frequencies. More than half of these show some positive effects. Surveys of this biological research have been conducted by several teams of experts and their opinions vary widely. Morton W. Miller and Gary E. Kaufman writing in the January/February edition of *Environment* ("High Voltage Overhead") say: "A review of the evidence relating to the possible environmental impacts associated with alternating current electric power transmission lines and, in particular, the biophysical and biological effects, suggests that concern about the deleterious consequences of power lines' electric and magnetic fields lacks scientific support."[15] However, other well-qualified people have reviewed the evidence and have reached conclusions diametrically opposed to those of Miller and Kaufman.

Beginning in 1975 the New York State Public Service Commission held hearings on the health and safety of 765 kv lines (Cases 26529 and 26559) for almost three years. Morton W. Miller was one of the expert witnesses employed to testify on behalf of Rochester Gas and Electric Corporation, Niagara Mohawk Power Corporation, and the Power Authority of the State of New York. Last August, after listening to approximately 13,000 pages of testimony on both sides of the case, the Staff of the Public Service Commission filed an Initial Brief. "The evidence presented," they said, "prompts us to conclude that biological effects will probably be induced in humans exposed to overhead lines and that such effects may be harmful."[16] They go on to identify 13 scientific studies which, in their opinion,

provide a solid body of evidence that electric and magnetic fields from 765 kv transmission lines will probably cause biological effects in humans. A long list of other studies is cited as providing supporting evidence for this conclusion. Each of these studies had been criticized in some way by the witnesses employed by the power companies in an attempt to explain away any positive findings. As the staff of the Commission said, "The applicants' witnesses have denied the validity and applicability of all of these studies to the transmission line situation. We could not accept the premise underlying their position, namely, that the work of 60 groups of respected researchers was scientifically unacceptable."[17]

Unfortunately, almost all of the research work that is currently in progress, as well as most of the surveys of existing literature, is directly or indirectly financed by the electric industry. It would be unrealistic to expect that results emerging from this industry-funded research would present an unequivocal case against the big transmission lines. There have been too many examples in recent years of "scientific studies" financed by some large company disproving any claims of deleterious effects caused by a product of that industry. Beginning in 1962 the tobacco industry has poured money into the attempt to discredit the scientific studies that have shown cigarettes to be a health hazard. Chemical companies have been putting a similar effort into "proving" that spray application of DDT and 2, 4, 5-T is not threatening to human beings.

In view of this situation, it is interesting to note, however, that a careful reading of the reports of studies that were funded by the electric industry do reveal a number of biological effects from exposure to electric fields. In an experiment on mice sponsored by American Electric Power Company and performed by Knickerbocker et al. in 1967,[18] the size of male offspring of mice exposed to strong electric fields was significantly reduced. The exposed mice were also observed to sleep more than the mice that had not been exposed. But these alterations in growth rate and activity were not followed up in spite of the fact that further studies were recommended by the researchers.

Many years later similar findings were observed in a project conducted by Westinghouse Electric Corporation for Electric Power Research Institute (which is totally funded by the electric industry). An interim report states: "Gross motor activity of birds from this study was measured during one-hour bouts on days 22,29 posthatching, after the birds had been removed from the electric field. Results were again clear; activity of exposed birds was reduced relative to the controls."[19] Changes in growth rate were also discovered. Growth enhancement occurred during the second week of exposure, but at the end of the 22-day exposure period no significant differences in weight were found. "It is now clear," say the authors, "that certain biological properties of plants and animals are affected by high-voltage AC electric fields."[20]

But the positive discovery of reduced activity was not followed up and was not mentioned by the researchers in their conclusions. On the other hand, the slight and transient tendency toward growth enhancement was emphasized. The authors sum up with the statement: "No detrimental effects of either brief or prolonged exposure to AC electric fields have yet been demonstrated in our laboratory."[21] It is apparent, of course, that no detrimental effects will be demonstrated by researchers who fail to follow up any evidence of such effects, who only pursue the experimental procedures that are revealing no effects or effects that can be interpreted as beneficial.

Evaluating the Results

Actually, the assumption that effects like growth enhancement may be beneficial is very questionable. Acceleration in growth might be advantageous in chickens grown for the food market but would certainly not be desirable for otherwise normal human beings. Since biological systems are finely adapted by the evolutionary process to the environment to which they are regularly exposed, any random and arbitrary change affecting a biological system is almost always detrimental. It certainly should be viewed with great suspicion until it is definitely proven to be harmless.

The discovery of increased sleepiness and decreased rate of activity are especially interesting because they corroborate the information from the studies on substation workers in Russia, where unnatural sleepiness and fatigue were among the most common symptoms reported by workers who had regularly been exposed to electric fields. Although these effects do not seem to be very serious in themselves, they may be symptoms of a more fundamental problem. As the Russian scientists suggest, the electric fields may interfere with the normal functioning of the central nervous system. A number of experiments conducted in the United States lend support to this hypothesis.

A few years ago American Electric Power Company provided assistance for a comprehensive review of the technical literature on the biological effects of electric and magnetic fields of extremely low frequency. This survey was performed by Asher R. Sheppard and Merril Eisenbud at the Institute of Environmental Medicine, New York University Medical Center, and the results were published in book form in 1977.[22] In their summarizing chapter the authors make the following statement: "The one firm conclusion that emerges from a review of the existing literature is that relatively weak electric or magnetic fields are capable of evoking neurophysiological or behavioral effects. This is suggested by the behavioral experiments on monkeys, biochemical studies of the calcium efflux in brain tissues, the experience of Soviet substation workers exposed to electric fields, and other industrial workers to magnetic fields and, by inference, by the preliminary evidence for both electric and magnetic effects on the steroid hormones in animals. The serum triglyceride increase could be fit into this pattern since the lipid metabolism is known to be under hormonal regulation which in turn is regulated by the central nervous system."[23]

(continued on page 37)

Danger: High Voltage

(continued from page 20)

Andrew A. Marino and Robert O. Becker, working at the Veterans Administration Hospital and Upstate Medical Center in Syracuse, New York, have found that rats exposed to a 60 Hz electric field for one month exhibited hormonal and biochemical changes similar to those caused by stress. The electric field to which the animals were exposed was comparable in strength to that produced at ground level by a typical 765 kv line. In another experiment they continuously exposed three generations of rats to the electric field and found increased infant mortality and severely stunted growth. "Our results," these scientists say, "appear to indicate that the applied electric field primarily affects the central nervous system and activates the stress-response mechanism. Chronic stress can produce a wide variety of diseases and pathological conditions."[24]

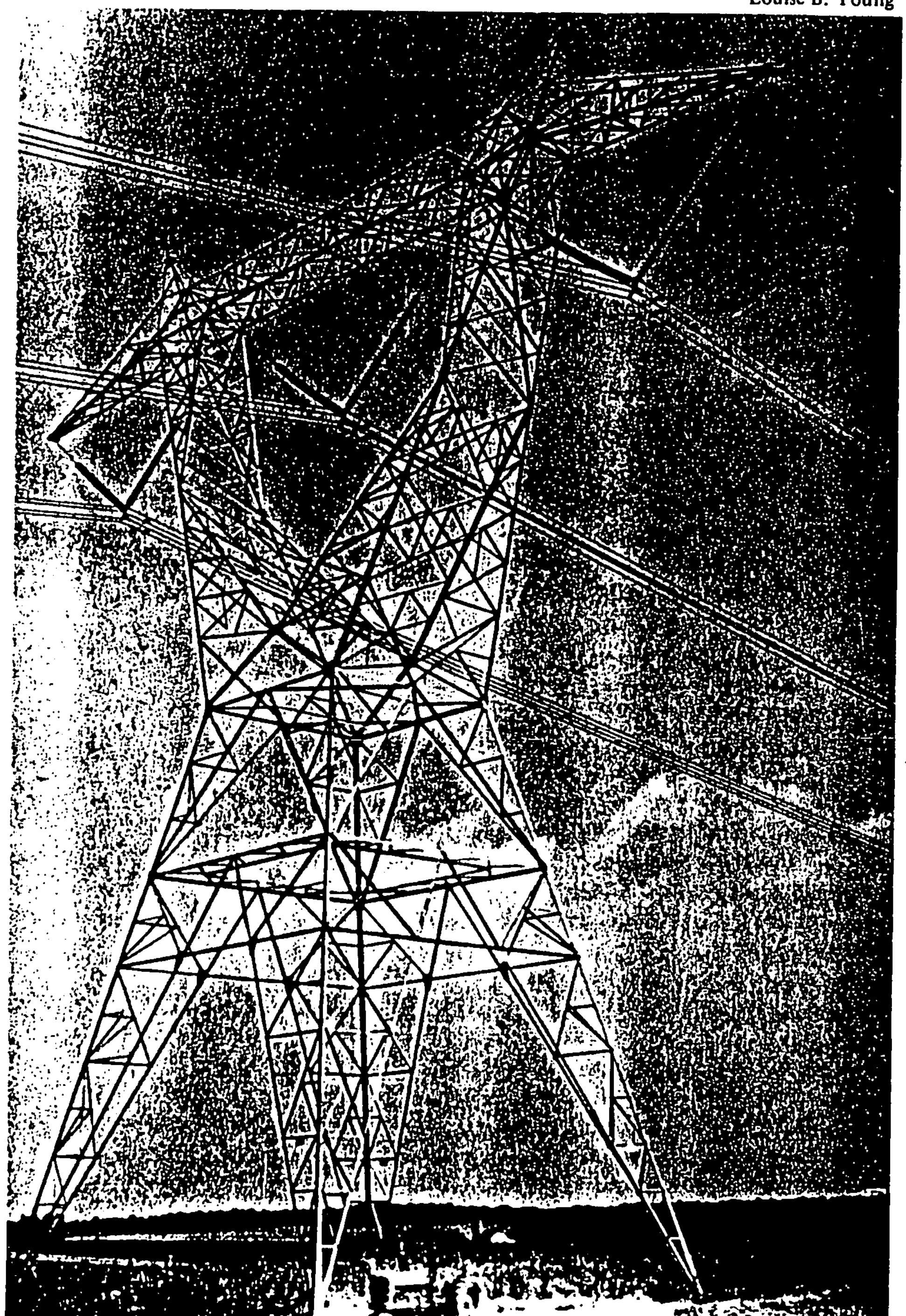
At Johns Hopkins Medical School, Donald S. Gann, a professor of surgery, designed laboratory experiments to test the effect of electric fields on some of the involuntary responses that are controlled by the central nervous system: arterial pressure, pulse rate, temperature, etc. In his first experiments he exposed anesthetized dogs for a five-hour period to fields of 15 kv/m. (This is just slightly more than the maximum fields that can occur at ground level under the 765 kv lines now in operation.) These dogs, as well as the control group, were then subjected to a small controlled hemorrhage in order to test the response of the nervous system to this artifically induced stimulus. Cardiovascular changes observed at the end of the hemorrhage were different in the exposed and unexposed groups. Mean arterial pressure fell an average of 5.9 mmHg in the control group and 16.0 mmHg in the exposed group. Arterial pulse pressure fell 0.9 mmHg in the control group and 10.9 mmHg in the exposed group. Heart rate decreased an average of 9.3 beats/minute in the control group but increased 57.5 beats/minute in the exposed group. These effects were statistically significant in a sample of the size tested.[25]

Funding for this project, originally provided by the Electric Power Research Institute, was terminated shortly after the report describing these initial experiments had been filed. However, Dr. Gann has been conducting some follow-up studies independently. He continues to get results consistent with his first experiments.[26] Research of this type—independent of funding by the electric industry—is very much needed to resolve the important health and safety questions.

The Null Hypothesis

Scientists who state that 60 Hz electric and magnetic fields of the strength caused by extra-high-voltage lines can-

Louise B. Young



It is now recognized that the biochemical mechanisms may be much more complicated than had previously been recognized. Drs. Becker and Marino have observed biological effects from electric fields which could demonstrate a trigger phenomenon.

not cause biological harm base their argument on unproven theoretical considerations. They point out that the only two known mechanisms by which an electric field can cause biological effects (bulk tissue heating and membrane excitation) cannot occur at the energy levels encountered under 765 kv lines (see Miller and Kaufman, "High Voltage Overhead"). These theories rest on assumptions that have recently been questioned.[27] It is now recognized that the biochemical mechanisms may be much more complicated and much more sensitive than had previously been supposed. Dr. Becker and Dr. Marino have observed biological effects from electric fields which, they believe, demonstrate a trigger phenomenon. In these reactions, the electromagnetic field does not supply the energy for a given process but merely furnishes the energy to control or trigger it.

At any rate, a theoretical argument should not take precedence over experimental evidence. A scientific theory is only valid as long as it accommodates the facts. When experimental evidence contradicts a previously accepted theory, the theory must be revised to explain the facts. Experimental evidence is not thrown out to preserve the theory.

It is true that science can never prove a null hypothesis, as Miller and Kaufman point out.[28] But a null hypothesis can be *disproven* by the discovery of just one firm positive fact. As we have seen, many experiments have turned up definite biological effects from exposure to 60 Hz electric and magnetic fields. Many facts disproving the null hypothesis have already been demonstrated and research on this subject is still in its infancy.

Until these issues are resolved there will surely be continued confrontations across the country as 765 kv lines and even higher voltage lines (1100 kv or even 1500 kv) are built across people's farms and vegetable gardens, between their houses and their barns, across their back yards and recreational areas. Responsible people who have considered the issue in some depth recognize that there is a human rights question involved here. In their recommended decision, the Administrative Law Judges in the New York State Hearings said: "What is necessary is to remove the involuntary feature, i.e., to insure that persons living or working near the line are not involuntarily exposed to danger and that persons who enter the right-of-way do so voluntarily with knowledge that chronic, long-term exposure may entail some risk."[29] Let us hope the nonviolent protests now taking place around the country will bring about an unbiased consideration of these problems.

NOTES

1. Hazards cited by Bonneville Power Administration in The Role of the Bonneville Power Administration in the Pacific Northwest Power Supply System, Including Its Participation in the Hydro-Thermal Power Program: A Program Environment and Planning Report, 1977, pp. vii, 58-59.

2. Testimony of Robert E. Tillman before the West Virginia Public Service Commission, Case No. 9003, March 14, 1978. See also Environmental Analysis for the Culloden-Gavin 765 kv Transmission Line, Appalachian Power Company, April 1977, p. 70.

3. T. Sterling, Primary Health Effects of 2,4,5-T, prepared for the Royal Commission Hearings on Herbicides and Pesticides, British Columbia, July 16, 1974, p. 15.

4. Testimony of Don W. Deno before the State of New York Public Service Commission, Cases 26529 and 26559, Common Record Hearings on Health and Safety of 765 kv Transmission Lines, Exhibit 5, Table 1.

5. J. E. Bridges, M. J. Frazier, and R. G. Hauser (consultant), A Summary of Work on the Effects of 60 Hz Electric Fields and Current on Implanted Cardiac Pacemakers, IIT Research Institute Project E 8167 (prepared as technical background for participants of EPRI sponsored seminar, February 23-24, 1978).

6. Bridges et al., p. 5.

7. Bridges et al., Table 1.1.

8. Bridges et al., p. 2.

9. V. P. Korobkova, Yu. A. Morozov, M. D. Stolarov, and Yu. A. Yakub, Influence of the Electric Field in 500 and 750 kv Switchyards on Maintenance Staff and Means for Its Protection, International Conference on Large High Tension Electric Systems (CIGRE), Paris, August-September, 1972.

10. Korobkova et al., p. 1.

11. Yu. L. Lyskov, Yu. S. Emma, and M. D. Stolyarov, "Electrical Field as a Parameter Considered in Designing Electric Power Transmission of 750 - 1150 kv; the Measuring Methods, the Design Practices and Direction of Further Research." Proceedings of the Symposium of EHV AC Power Transmission, held by the Joint American-Soviet Committee on Cooperation in the Field of Energy, Washington, D. C., February 17-27, 1975, p. 57.

12. Lyskov et al., pp. 65-67.

13. W. B. Kouwenhoven, O. R. Langworthy, and M. L. Singewald, "Medical Evaluation of Men Working in AC Electric Fields," IEEE Transactions, PAS-86, April 1967, p. 510. And M. L. Singewald, O. R. Langworthy, and W. B. Kouwenhoven, "Medical Follow-up Study of High Voltage Linemen Working in AC Electric Fields," IEEE Transactions, PAS-92, July-August 1973, pp. 1307-1309.

14. Singewald et al., p. 1309.

15. Morton W. Miller, and Gary E. Kaufman, "High Voltage Overhead," Environment, January/February 1978, p. 6.

16. Robert A. Simpson, Staff's Initial Brief, State of New York Public Utility Commission, Cases 26529 and 26559 on the Health and Safety Effects of 765 kv Transmission Lines (Combined Record Hearings), August 30, 1977, p. 73.

17. Simpson, p. 61.

18. G. G. Knickerbocker, W. B. Kouwenhoven, and H. Barnes, "Exposure of Mice to a Strong AC Electric Field—An Experimental Study," IEEE, PAS-86, April 1967, pp. 498-505.

19. J. W. Bankoske, G. W. McKee, and H. B. Graves, Ecological Influence of Electric Fields, Interim Report on EPRI EA-178, Project 129, Westinghouse Electric Corporation, September 1976, p. 30.

20. Bankoske et al., p. 38.

21. Bankoske et al., p. 38.

22. Asher R. Sheppard, and Merril Eisenbud, Biological Effects of Electric and Magnetic Fields at Extremely Low Frequency, New York University Press, New York, 1977.

23. Sheppard and Eisenbud, p. 2-29.

24. Robert O. Becker and A. Marino, "Electromagnetic Pollution," The Sciences 18 (January 1978): 15.

25. Donald S. Gann, "Final Report, Electric Power Research Institute Project," RP 98-02.

26. Personal communication with Dr. Donald Gann, March 1977.

27. See for example, Frances Schmitt and Barry H. Smith, "Electrotonic Processing of Information in Brain Cells," Science, 193 (July 9, 1976): 114-120.

28. Miller and Kaufman, p. 33.

29. "Recommended Decision by Administrative Law Judges Matias and Colbeth, Cases 26529 and 26559 on the Health and Safety Effects of 765 kv Transmission Lines (Combined Record Hearings), State of New York Public Service Commission," January 20, 1978, p. 144.

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109

Grounding and Shielding

William G. Duff
Computer Sciences Corporation

Grounding and shielding are two very important factors that must be considered during the design of electronic circuits. Current trends in the electronics industry (such as increases in the number of electronic equipments, reliance on electronic devices in critical applications, higher clock frequencies of computing devices, higher power levels, lower sensitivities, increased packaging densities, use of plastics, etc.) will tend to create more electromagnetic interference (EMI) problems. To avoid problems, EMI control measures must be incorporated into circuit design.

109.1 Grounding[1]

Grounding is one of the least understood and most significant factors in many EMI problems. The primary purposes for grounding circuits, cables, equipments, and systems are to prevent a shock hazard; to protect circuits and equipments; and to reduce EMI due to electromagnetic field, common ground impedance, or other forms of interference coupling. The EMI part of the problem is emphasized in this section.

Characteristics of Ground Conductors

Ideally, a ground conductor should provide a zero-impedance path to all signals for which it serves as a reference. If this were the situation, signal currents from different circuits would return to their respective sources without creating unwanted coupling between circuits. Many interference problems occur because designers treat the ground as ideal and fail to give proper attention to the actual characteristics of the ground conductor.

A commonly encountered situation is that of a ground conductor running along in the proximity of a ground plane as illustrated in Fig. 109.1. The ground conductor and ground plane may be

[1]The material on grounding was adapted from Duff [1989] courtesy of Interference Control Technologies.

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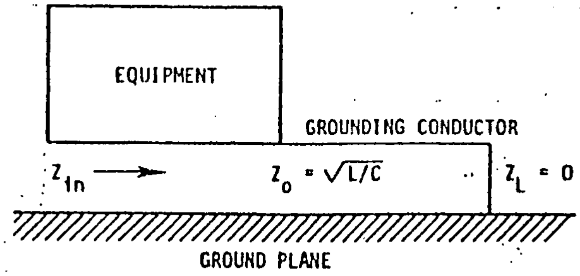


Figure 109.1 Idealized equipment grounding.

represented as a short-circuited transmission line. At low frequencies the resistance of the ground conductor will predominate. At higher frequencies the series inductance and the shunt capacitance to ground will become significant and the ground conductor will exhibit alternating parallel and series resonances as illustrated in Fig. 109.2. To provide a low impedance to ground, it is necessary to keep the length of the grounding conductor short relative to wavelength (i.e., less than 1/20 of the wavelength).

Ground-Related EMI Coupling

Ground-related EMI involves one of two basic coupling mechanisms. The first mechanism results from circuits sharing the ground with other circuits. Figure 109.3 illustrates EMI coupling between culprit and victim circuits via the common-ground impedance. In this case, the interference current (I_{c_g}) flowing through the common-ground impedance (Z_g) will produce an interfering signal voltage (V_i) in the victim circuit. This effect can be reduced by minimizing or eliminating the common-ground impedance.

The second EMI coupling mechanism involving ground is a radiated mechanism whereby the ground loop, as shown in Fig. 109.4, acts as a receiving or transmitting antenna. For this EMI coupling mechanism the induced EMI voltage (for the susceptibility case) or the emitted EMI field

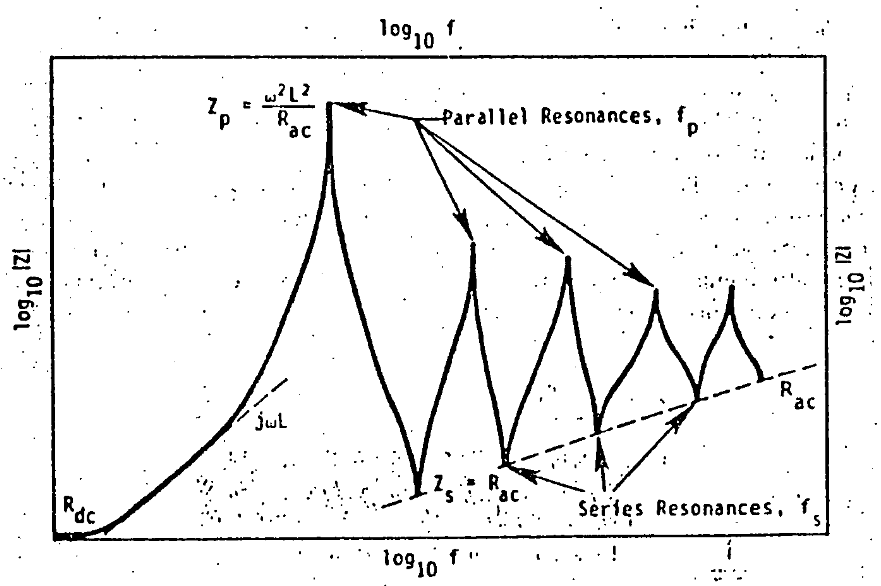
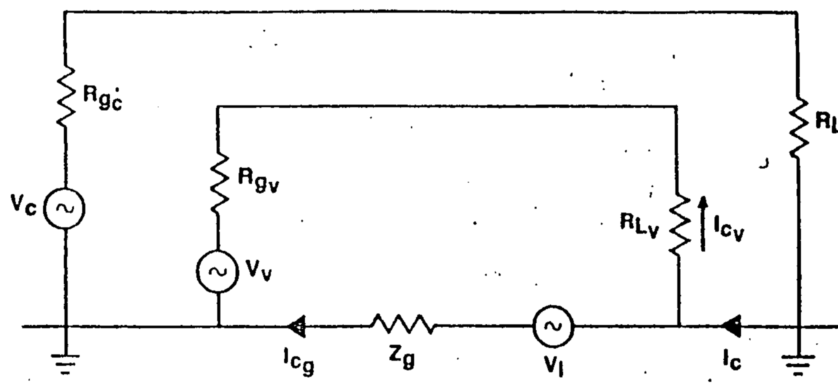


Figure 109.2 Typical impedance versus frequency behavior of a grounding conductor.



$$Z_g << R_{gv} + R_{Lv}$$
$$\therefore I_{cv} << I_{cg} \ \& \ I_{cg} \simeq I_c$$

Figure 109.3 Common-ground impedance coupling between circuits.

(for the emission case) is a function of the EMI driving function (field strength, voltage or current), the geometry and dimensions of the ground loop, and the frequency of the EMI signal. Radiated effects can be minimized by routing conductors close to ground and minimizing the ground-loop area.

It should be noted that both the conducted and radiated EMI coupling mechanisms identified earlier involve a "ground loop." It is important to recognize that ground loop EMI problems can exist without a physical connection to ground. In particular, at RF frequencies, capacitance-to-ground can create a ground loop condition even though circuits or equipments are floated with respect to ground.

Grounding Configurations

A typical electronic equipment may have a number of different types of functional signals as shown in Fig. 109.5. To mitigate interference due to common-ground impedance coupling, as many separate grounds as possible should be used.

The grounding scheme for a collection of circuits within an equipment can assume any one of several configurations. Each of these configurations tends to be optimum under certain conditions and may contribute to EMI problems under other conditions. In general, the ground configurations are a floating ground, a single-point ground, a multiple-point ground, or some hybrid combination.

A floating ground configuration is illustrated in Fig. 109.6. The signal ground is electrically isolated from the equipment ground and other conductive objects. Hence, equipment noise currents present in the equipment and power ground will not be conductively coupled to the signal circuits.

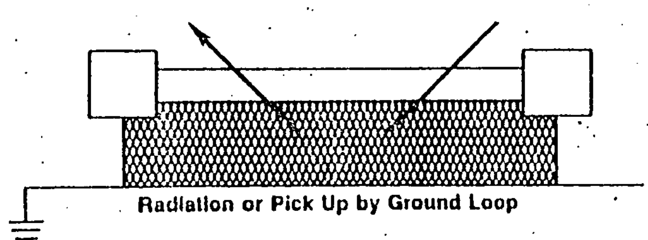


Figure 109.4 Common-mode radiation into and from ground loops.

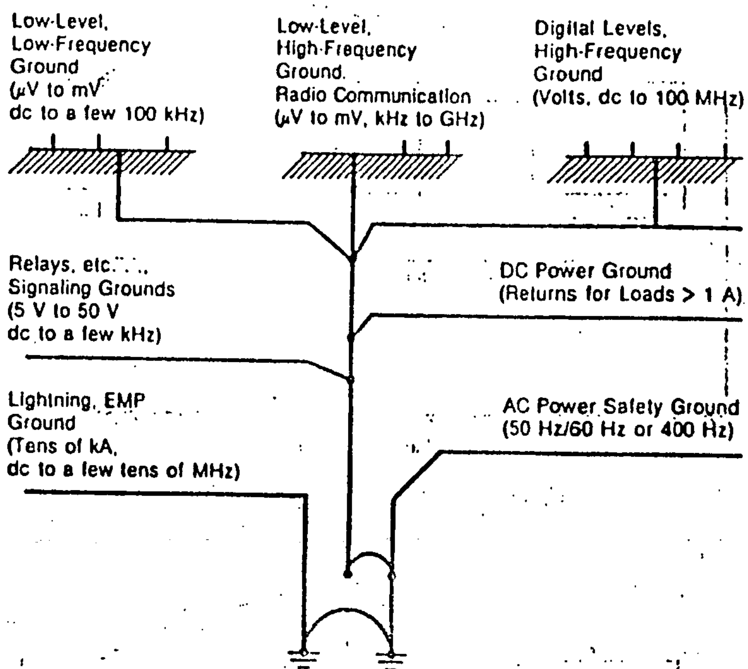


Figure 109.5 Grounding hierarchy.

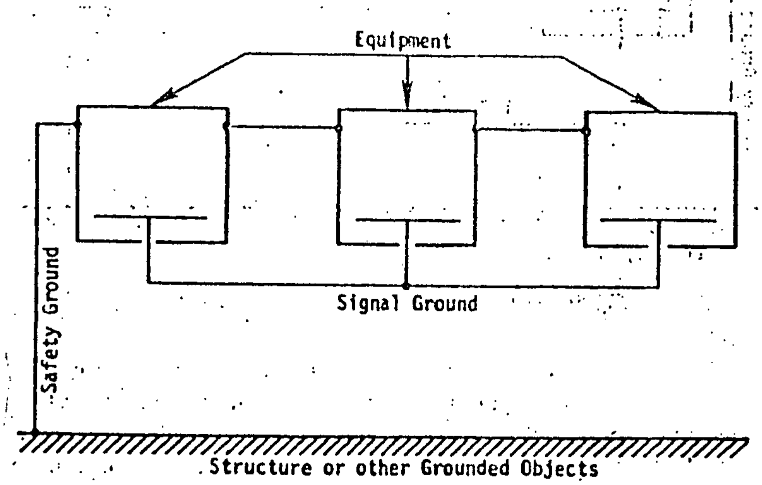


Figure 109.6 Floating signal ground.

The effectiveness of floating ground configurations depends upon their true isolation from other nearby conductors; that is, to be effective, floating ground systems must really float. It is often difficult to achieve and maintain an effective floating system. A floating ground configuration is most practical if only a few circuits are involved and power is supplied from either batteries or DC-to-DC converters.

A single-point ground configuration is illustrated in Fig. 109.7. An important advantage of the single-point configuration is that it helps control conductively coupled interference. As illustrated in Fig. 109.7, EMI currents or voltages in the equipment ground are not conductively coupled into the signal circuits via the signal ground. Therefore, the single-point signal ground network minimizes the effects of any EMI currents that may be flowing in the equipment ground.

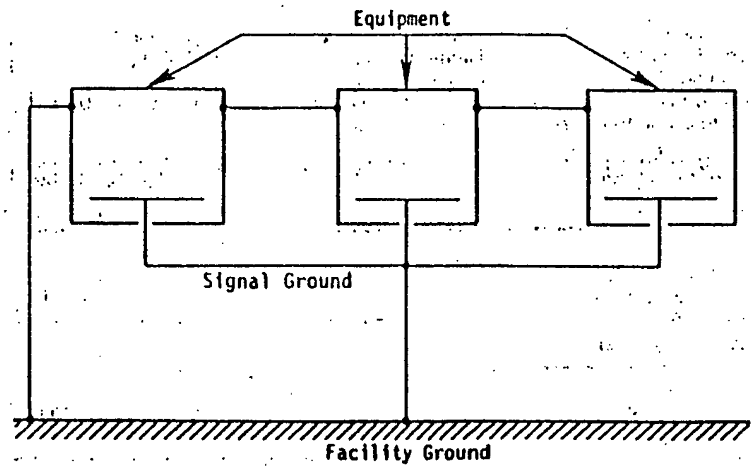


Figure 109.7 Single-point signal ground.

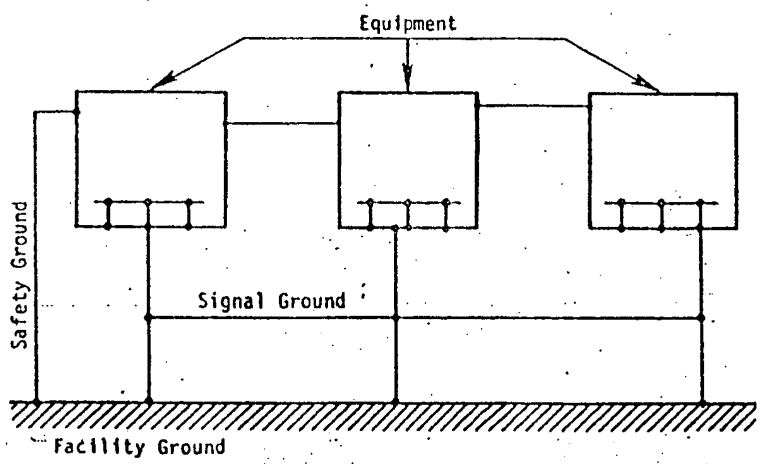


Figure 109.8 Multiple-point ground configuration.

The multiple-point ground illustrated in Fig. 109.8 is the third configuration frequently used for signal grounding. With this configuration, circuits have multiple connections to ground. Thus, in an equipment, numerous parallel paths exist between any two points in the multiple-point ground network. Multipoint grounding is more economical and practical for printed circuits and integrated circuits. Interconnection of these components through wafer risers, mother boards, and so forth should use a hybrid grounding approach in which single-point grounding is used to avoid low-frequency ground loops and/or common-ground impedance coupling; multipoint grounding is used otherwise.

Summary of Grounding Considerations

A properly designed ground configuration is one of the most important engineering elements in protecting against the effects of EMI. The ground configuration should provide effective isolation between power, digital, high-level analog, and low-level analog signals. In designing the ground it is essential to consider the circuit, signal characteristics, equipment, cost, maintenance, and so forth. In general, either floating or single-point grounding is optimum for low-frequency situations and

multiple-point grounding is optimum for high-frequency situations. In many practical applications a hybrid ground approach is employed to achieve the single-point configuration for low frequencies and the multiple-point configuration for high frequencies.

109.2 Shielding[2]

Shielding is one of the most effective methods for controlling radiated EMI effects at the component, circuit, equipment, subsystem, and system levels. The performance of shields is a function of the characteristics of the incident electromagnetic fields. Therefore, shielding considerations in the near-field region of an EMI source may be significantly different from shielding considerations in the far-field region.

Shielding Theory

If a metallic barrier is placed in the path of an electromagnetic field as illustrated in Fig. 109.9, only a portion of the electromagnetic field may be transmitted through the barrier. There are several effects that may occur when the incident wave encounters the barrier. First, a portion of the incident wave may be reflected by the barrier. Second, the portion of the incident wave that is not reflected will penetrate the barrier interface and may experience absorption loss while traversing the barrier. Third, additional reflection may occur at the second barrier interface, where the electromagnetic field exits the barrier. Usually this second reflection is insignificant relative to the other effects that occur and may be neglected.

The shielding effectiveness of the barrier may be defined in terms of the ratio of the impinging field intensity to the exiting field intensity. For high-impedance electromagnetic fields or plane waves, the shielding effectiveness is given by

$$\mathrm{SE}_{\mathrm{dB}} = 20\log\left(\frac{E_1}{E_2}\right) \qquad (109.1)$$

where E_1 is the impinging field intensity in volts per meter and E_2 is the exiting field intensity in volts per meter. For low-impedance magnetic fields, the shielding effectiveness is defined in terms of the ratio of the magnetic field strengths.

The total shielding effectiveness of a barrier results from the combined effects of reflection loss and absorption loss. Thus, the shielding effectiveness, S, in dB is given by

$$S_{\mathrm{dB}} = R_{\mathrm{dB}} + A_{\mathrm{dB}} + B_{\mathrm{dB}} \qquad (109.2)$$

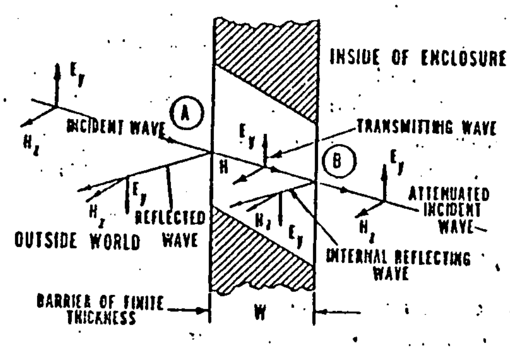


Figure 109.9 Shielding of plane waves.

[2]The material on shielding was adapted from Duff [1991] courtesy of Interference Control Technologies.

where R_{dB} is the reflection loss, A_{dB} is the absorption loss, and B_{dB} is the internal reflection loss. Characteristics of the reflection and absorption loss are discussed in the following sections.

Reflection Loss

When an electromagnetic wave encounters a barrier, a portion of the wave may be reflected. The reflection occurs as a result of a mismatch between the wave impedance and the barrier impedance. The resulting reflection loss, R, is given by

$$\begin{aligned} R_{dB} &= 20\log_{10}\frac{(K+1)^2}{4K}, \qquad K = \frac{Z_w}{Z_b} \\ &\approx 20\log_{10}\left(\frac{Z_w}{4Z_b}\right), \qquad K \geq 10 \end{aligned} \tag{109.3}$$

where Z_w is the wave impedance $= E/H$, and Z_b is the barrier impedance.

Absorption Loss

When an electromagnetic wave encounters a barrier, a portion of the wave penetrates the barrier. As the wave traverses the barrier, the wave may be reduced as a result of the absorption loss that occurs in the barrier. This absorption loss, A, is independent of the wave impedance and may be expressed as follows:

$$A_{dB} = 8.68t/\delta = 131t\sqrt{f_{MHz}\mu_r\sigma_r} \tag{109.4}$$

where t is the thickness in mm, f_{MHz} is the frequency in MHz, μ_r is the permeability relative to copper, and σ_r is the conductivity relative to copper.

Total Shielding Effectiveness

The total shielding effectiveness resulting from the combined effects of reflection and absorption loss are plotted in Fig. 109.10 for copper and iron materials having thicknesses of 0.025 mm and 0.8 mm, having electric and magnetic fields and plane-wave sources, and having source-to-barrier distances of 2.54 cm and 1 meter.

Shielding Materials

As shown in Fig. 109.10, good shielding efficiency for plane waves or electric (high-impedance) fields is obtained by using materials of high conductivity such as copper and aluminum. However, low-frequency magnetic fields are more difficult to shield because both the reflection and absorption loss of nonmagnetic materials, such as aluminum, may be insignificant. Consequently, to shield against low-frequency magnetic fields, it may be necessary to use magnetic materials.

Conductive Coatings

Conductive coatings applied to nonconductive materials such as plastics will provide some degree of EMI shielding. The principal techniques for metalizing plastic are the following:

- Conductive paints
- Plating (electrolytic)

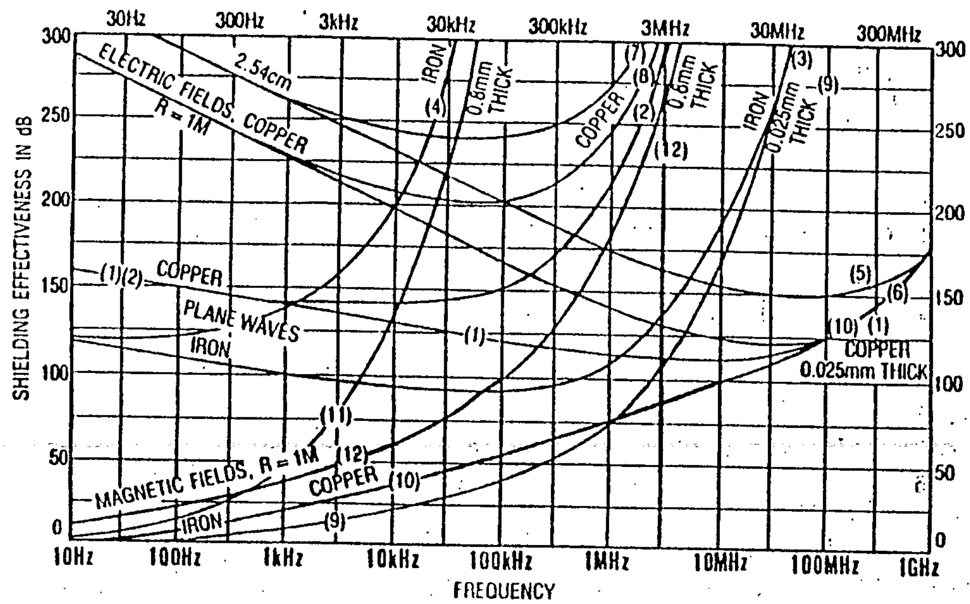


Figure 109.10 Total shielding effectiveness.

- Electroless plating
- Flame spray
- Arc spray
- Ion (plasma torch) spray
- Vacuum deposition

Because the typical conductive coatings provide only a thin film of conductive material, the shielding results from reflection losses that are determined by the ratio of the wave impedance to the conductive barrier impedance. The surface resistance (in ohms per square) will determine shielding effectiveness. Figure 109.11 shows comparative data for shielding effectiveness for various conductive coatings. The most severe situation (i.e., a low-impedance magnetic field source) has been assumed.

Aperture Leakages

Various shielding materials are capable of providing a high degree of shielding effectiveness under somewhat idealized conditions. However, when these materials are used to construct a shielded housing, the resulting enclosure will typically have holes and seams that may severely compromise the overall shielding effectiveness.

Figure 109.12 shows a rectangular aperture in a metal (or metalized) panel. A vertically polarized incident electric field will induce currents in the surface of the conductive panel. If the aperture dimensions are much less than a half wavelength, the path around the slot will provide a low impedance to the induced currents and, as a result, the aperture leakage will be small. On the other hand, as the aperture dimensions approach a half wavelength, the path around the slot will provide a high impedance to the induced currents and the aperture leakage will be significant. An aperture with dimensions equal to or greater than a half wavelength will provide almost no shielding (i.e., the incident field will propagate through the aperture with very little loss). In general, the shielding effectiveness of a conductive panel with an aperture may be approximated by

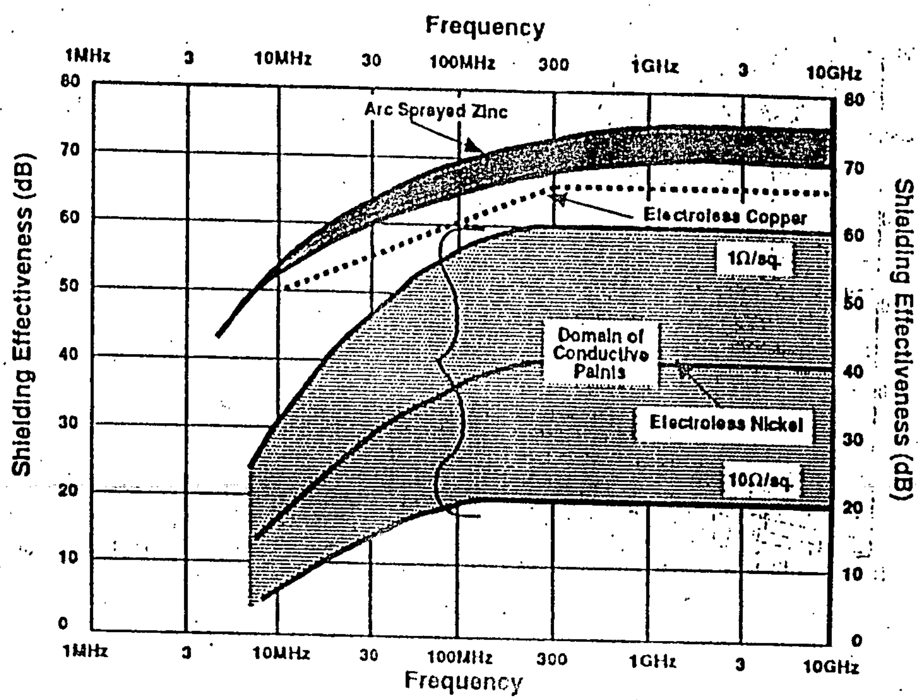


Figure 109.11 Shielding of conductive coatings. (By standard. 30 cm distance test. Near field attenuation is given against H field.) For paints, thickness is typically 2 mil. = .05 mm.

the following equation:

$$SE_{dB} \cong 100 - 20\log L_{mm} \times F_{MHz} + 20\log\left(1 + \ln\frac{L}{S}\right) \tag{109.5}$$

To maintain shielding integrity for an equipment enclosure, it may be necessary to provide EMI protection for the apertures.

Summary of Shielding Considerations

Shielding can provide an effective means of controlling radiated EMI effects. To ensure that shielding effectiveness requirements are met, it is necessary to

- Select,a material that is capable of providing the required shielding
- Minimize the size of openings to control aperture leakages

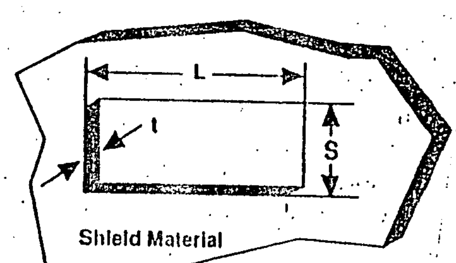


Figure 109.12 Slot and aperture leakage.

- Subdivide large openings into a number of smaller ones
- Protect leaky apertures (e.g., cover with wire screen)
- Use EMI gaskets on leaky seams
- Filter conductors at points where they enter or exit a shielded compartment

Defining Terms

Ground: Any reference conductor that is used for a common return.

Near-field/far-field transition distance: For electrically small radiators (i.e., dimensions ≪ wavelength), the near-field/far-field transition occurs at a distance equal to approximately one sixth of a wavelength from the radiating source.

Plane wave: Far-field electromagnetic wave with an impedance of 377 ohms in air.

Reference: Some object whose potential (often 0 volts with respect to earth or a power supply) is the one to which analog and logic circuits, equipments, and systems can be related or benchmarked.

Return: The low (reference) voltage side of a wire pair (e.g., neutral), outer jacket of a coax, or conductor providing a path for intentional current to get back to the source.

Wavelength: The distance corresponding to a period for the electromagnetic wave spatial variation. Wavelength (meters) = 300/frequency (MHz).

References

Denny, H. W. 1983. *Grounding for the Control of EMI.* Interference Control Technologies, Gainesville, VA.

Duff, W. G. 1989. *Grounding for the Control of EMI.* EMC EXPO 89 Symposium Record. Interference Control Technologies, Gainesville, VA.

Duff, W. G. 1991. *Electromagnetic Shielding.* EMC EXPO 91 Symposium Record. Interference Control Technologies, Gainesville, VA.

Mardiguian, M. 1988. *Grounding and Bonding, Volume 2—A Handbook Series on Electromagnetic Interference and Compatibility.* Interference Control Technologies, Gainesville, VA.

White, D. R. J. and Mardiguian, M. 1988. *Electromagnetic Shielding, Volume 3—A Handbook Series on Electromagnetic Interference and Compatibility.* Interference Control Technologies, Gainesville, VA.

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